Testing Advanced Distributed Simulation for Use in Electronic Warfare Test and Evaluation

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ABSTRACT: *The JADS JT&E program is an OSD sponsored Joint-Service test designed to determine how well an emerging technology - Advanced Distributed Simulation (ADS) - can support DoD test and evaluation (T&E) activities. The two-phase ADS test using an Electronic Warfare (EW) system will investigate the present utility of ADS for T&E, identify the critical constraints, concerns, and methodologies when using ADS for T&E; and identify the requirements that must be introduced in ADS systems if they are to support a more complete T&E capability in the future. The emphasis of the JADS EW test is not on evaluating the EW system performance in use as a test vehicle; rather, the emphasis of the test is on the performance of the ADS components and their relative contribution to EW systems T&E. The term ADS (which includes Distributed Interactive Simulation as a subset) is intended to support a mixture of live, virtual, and constructive entities. The ADS-oriented test approach will investigate numerous issues from the T&E perspective including distributed test control and analysis, network performance, relationships between data latencies, ADS induced data anomalies, use of the High Level Architecture (HLA), and Run Time Infrastructure (RTI). Time, cost, and complexity, as well as validity and credibility of the data are part of the evaluation. A series of tests have been designed which will support comparison of data and results obtained from open air range EW testing with two ADS-based tests.*

This paper focuses on the two ADS-based tests to evaluate the utility of Advanced Distributed Simulation (ADS) to support an Electronic Warfare system test. The paper describes the test objectives, scope, and test design process for creating a unique virtual EW test environment of linked components. Details describing the test methodology, the ADS test architecture for testing an EW system, and use of DMSO's High Level Architecture are provided.

1. Background

Modeling and simulation plays a significant role throughout the EW test process and can uniquely support system T&E prior to the development of actual hardware. The ability to demonstrate the utility of a new EW device prior to investing in hardware development has long been a developer's dream . However, limitations in modeling and simulation to support EW testing (e.g., lack of fidelity in replicating certain complex EW functions and a corresponding wide confidence interval when using modeling and simulation to predict absolute performance or effectiveness of EW systems) have precluded achieving the dream. Use of ADS to link models, simulations, and actual hardware in real time promises to provide an EW test architecture with a larger number of the available test resources for use in the EW test process and an enhanced test environment for future EW system T&E. ADS could allow us to achieve the dream.

While it is relatively simple to conceptualize an ADS environment to support EW T&E, it is relatively difficult to show this utility in the real world. There are significant technical challenges to fully implementing ADS in EW T&E that must be evaluated. The achievable performance that can be obtained from ADS to link models, simulations, and actual hardware to support the EW test process must be determined. In addition to measuring performance, there are significant

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design and implementation issues that need to be addressed in the evaluation of ADS.

The JADS EW test design, while focused on evaluating the utility of Advanced Distributed Simulation, incorporates the High Level Architecture and Runtime Infrastructure to provide some initial insights into applying the HLA processes and products to an actual weapons system test. The HLA is an integral component of JADS EW test, and represents a key element of the building block approach JADS will use to determine the current capability ADS provides for EW T&E. JADS is applying the experience and lessons learned from the HLA Engineering Proto-federation (EPF). The EPF was designed (as one of four simulation prototypes) to evaluate the suitability of the HLA and prototype RTI to support high fidelity simulations employed in a realistic test and engineering situation. JADS is working with former members of the EPF, leveraging experience and building on the EPF architecture for the JADS EW test federation.

2. Test Process

Because of widespread interest in using ADS technology to support T&E, JADS is chartered to investigate the utility of ADS for both developmental test and evaluation (DT&E) and operational test and evaluation (OT&E). JADS was tasked to develop the program test design for an ADS based test of an EW system and specifically called for the use of an airborne self-protection jammer as the system under test (SUT). This test was subsequently approved for execution in July 1996. Early in the test concept development phase, JADS conducted a comprehensive survey of DoD's ongoing efforts to employ ADS technology in EW testing. The survey showed that while many of the major T&E centers were experimenting with ADS to support various facets of EW testing, these efforts tended to be technology demonstrations focused on resolving limitations within the individual test centers' infrastructure. None of the efforts where focused on answering the question posed to the JADS JT&E: "How could ADS be used to address the inherent shortfalls in EW T&E?" Each of the military services have test facilities and internal test processes designed for T&E of a wide range of EW systems. While each Service's facilities and procedures are tailored to match unique Service requirements, the overall process for testing EW systems is similar across the Services. Figure 1 shows the EW Systems Life Cycle and the test and evaluation resources used to support the process.

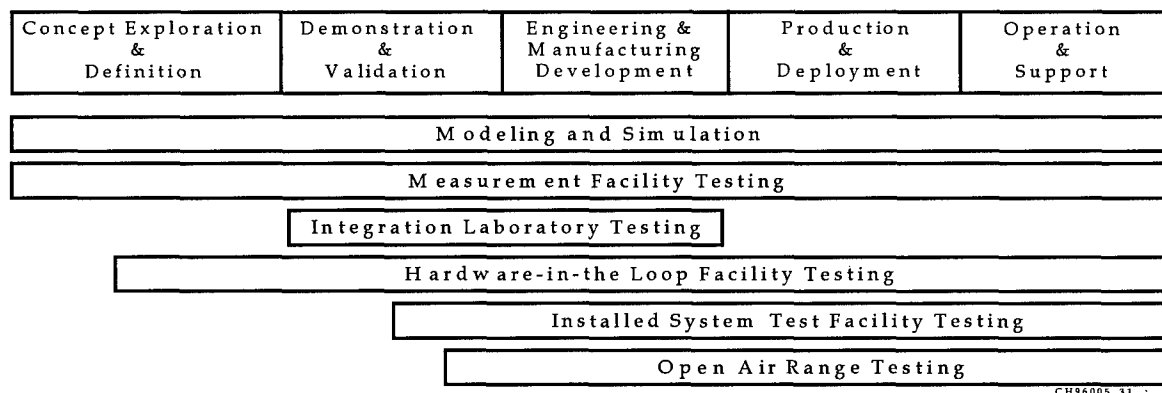| Concept Exploration & Definition	Demonstration & Validation	Engineering & Manufacturing Development	Production & Deployment	Operation & Support
Modeling and Simulation				
Measurement Facility Testing				
Integration Laboratory Testing				
Hardware-in-the Loop Facility Testing				
Installed System Test Facility Testing				
Open Air Range Testing				

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Figure 1 - EW Systems Development and T&E Processes

The existing EW test process uses a combination of modeling and simulation with measurement facility, system integration laboratory, hardware-in-the-loop, installed system and open air range testing, and is designed to make the most of existing T&E technologies and resources to provide a comprehensive evaluation of EW systems. The process is a building block approach designed to build upon the strengths and minimize the weaknesses of each of the available test resources. However, there are a number of known weaknesses in the process. In addition to the limitations in the individual resources

described above, two interrelated areas of particular concern in EW effectiveness testing are: problems associated with correlating and interpreting EW test results, and the availability of appropriate resources at the right levels of fidelity to support required T&E activities.

2.1 ADS in the EW Test Process

Using advanced distributed simulation to link models, simulations, and actual hardware in real time, it is easy to postulate an ADS test environment that combines the available test resources currently used in the EW test process to produce an enhanced test environment that can be used to support EW system test and evaluation.

2.2 An ADS Architecture for EW

Effective EW system testing requires appropriate representations of the system under test (SUT), and the relevant portions of the operational environment. This is true for all phases of testing from modeling and simulation to flight test. JADS has divided the fundamental building blocks required to accomplish full up mission level EW testing into six functional areas:

a. Representation of the system under test.
b. Representation of the host aircraft
c. Representation of the enemy command and control structure
d. Representation of the friendly command and control structure
e. Representation of other "reactive' red players (terminal threats, airborne interceptors, etc.)
f. Representation of other "reactive' blue players (standoff jamming, other players in a formation, etc.)

Multiple representations of each of these fundamental building blocks are currently available to the EW tester in each of the three categories of representation recognized in the ADS community: constructive (e.g., digital models), virtual (e.g., Hardware-in-the-Loop test assets that are not constrained in time/space representation), and live players (e.g., open air range assets or real aircraft). Using an ADS linking architecture, it is possible to link the fundamental building blocks required to conduct an EW test in any of the three representations described above. This is depicted in figure 2.
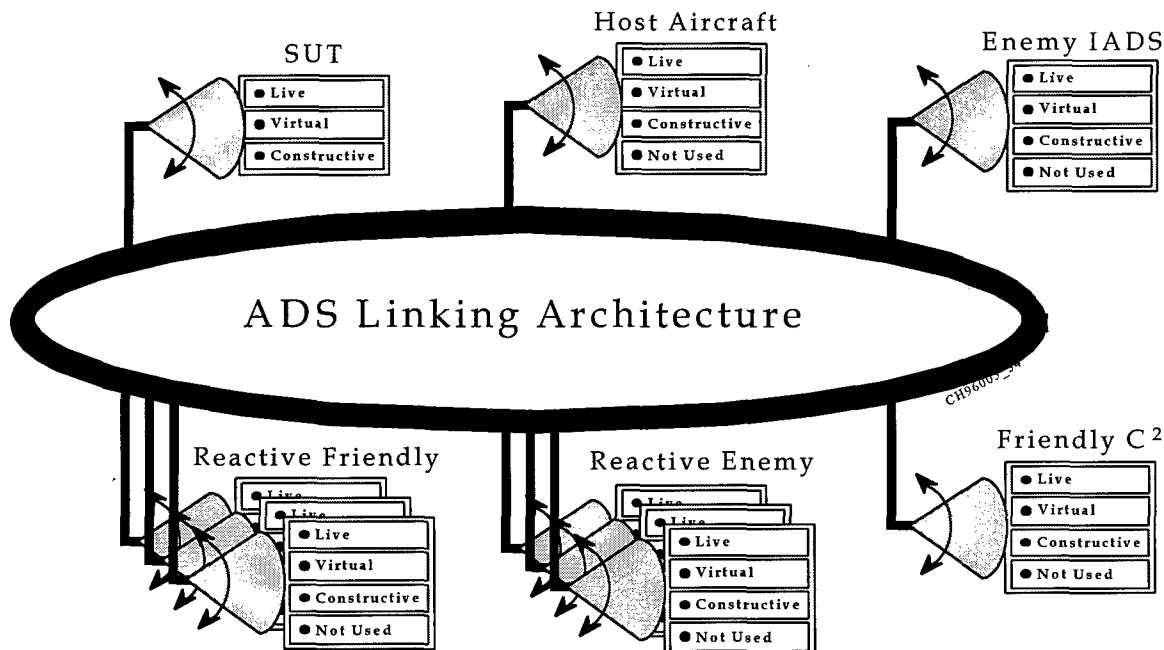

Figure 2 - Using an ADS Linking Architecture for EW T&E

3. JADS EW T&E Objectives

While it is relatively simple to conceptualize an ADS environment to support EW T&E, it is relatively difficult to show this utility in the real world. There are significant technical challenges to fully implementing ADS in EW T&E that must be evaluated. The achievable performance that can be obtained from ADS to support the EW test process must be determined. Programmatic issues, such as cost and schedule impacts, must be considered. The objective of the JADS EW T&E is to address these questions and thus assess the utility of ADS to EW test and evaluation.

This JADS EW test design contains the critical ADS-related test activities and applies a building block approach to determining the extent to which ADS may be used in EW T&E. The issues and objectives developed for the JADS EW test are listed in the table below.

Table 1 - JADS EW Issues and Objectives

Issues	Objectives
Issue 1: What is the present utility of ADS, including DIS, for T&E ?	Objective 1-1: Assess the validity of data from tests using ADS during test execution. Objective 1-2: Assess the benefits of using ADS in T&E
Issue 2: What are the critical constraints, concerns, and methodologies when using ADS for T&E ?	Objective 2-1: Assess the critical constraints and concerns in ADS performance for T&E. Objective 2-2: Assess the critical constraints and concerns in ADS support systems for T&E. Objective 2-3: Develop and assess methodologies associated ADS for T&E.
Issue 3: What are the requirements that must be introduced into ADS systems if they are to support a more complete T&E capability in the future ?	Objective 3-1: Identify requirements for ADS systems that would provide a more complete T&E capability in the future.

LIMITATIONS & CONSTRAINTS

A complete assessment of ADS utility to the EW test process would require the application of the technology to all phases of the test process as applied to the full range of EW systems. While feasible, such a test of the technology is costly. Therefore, this test design was developed by applying a set of goals and constraints relative to test content, cost, schedule, and personnel. The test content was reduced to focus on the inherent limitations of the EW test process–correlation, resources, and fidelity–and address the technical issues listed below:

- High-fidelity, real-time modeling to support ADS
- Timing and synchronization of EW engagements in a linked environment
- Signal verification instrumentation
- ADS impact on test results
- Closed-loop effectiveness testing of installed system in a linked environment

4. Self-protection Jammer Test Approach

The test has been designed as a three-phase test focusing on the EW test process during the development of a SPJ.

Phase I: Flight test of a SPJ on an Open Air Range (OAR). The purpose of this test is to establish a baseline of environment and performance data which will be used to develop the ADS test environment for the following phases and will be the basis for determining the validity of the ADS test results. Additionally, the performance data collected will be the baseline for attempting to correlate the data across all three phases of the test. Although flight testing of the SPJ would normally occur at the end of the EW test process, we are conducting this phase first to collect the data required to replicate the test in the ADS environment.

Phase II: ADS test using a high-fidelity real-time digital system model (DSM) of the SPJ. The threat laydown from the OAR will be

replicated in the synthetic ADS environment including links with HITL terminal threats and a constructive model of an IADS. The SUT will be flown, via a scripted flight profile developed from the actual OAR flights, through the Integrated Air Defense System (IADS), engaging the high-fidelity terminal threats. In the normal EW test process, the DSM would be developed as a tool for requirements analysis early in the development of a new system and would not typically be tested in a high-fidelity threat environment. This phase will evaluate the ability to apply increased fidelity and resources through ADS early in the development cycle and to develop requirements for a new system through actual effectiveness testing of a digital model of the proposed EW system, a true test-before-you-build capability.

Phase III: ADS test using the SPJ installed on an actual aircraft located in an ISTF. The facility will be linked with HITL threats and the constructive model of the IADS using the same threat laydown as the previous tests and controlled by the same scripted flight profile. In the normal EW process, ISTF testing is used late in the development cycle to measure the effect of aircraft systems on the performance of the SPJ. This type of testing does not normally provide a detailed measure of the effectiveness of the jammer against a variety of threats. This test will not only evaluate the installed system in the normal mode but will also evaluate the ability to perform closed-loop effectiveness testing of the jammer installed on the aircraft prior to flight test.

4.1 JADS EW SPJ Test Articles

A key requirement for the test designer in an ADS environment is to tailor the environment based on the maturity of the system, the test objectives, and program constraints. We have applied a similar approach to the selection of components for this test.

EW SUT : We selected the ALQ-131 Block II with reprogrammable processor as the SUT. Key to its selection was the availability of a DSM. During the original development of the ALQ-131 Block II R/P, Georgia Tech Research Institute (GTRI) developed a digital model of the system which simulates all hardware and processing and will emulate the operational flight program of the SPJ.

Host Aircraft : Along with compatibility with the SUT, we required the selected host aircraft to be a non-developmental penetrator. The aircraft needed to be readily available and capable of being easily supported and instrumented for the tests. The logical choice was the F-16C.

Integrated Air Defense System (IADS) : A depiction of the enemy IADS can be provided at several levels of fidelity. Each of these levels are suitable for the SPJ test and we will use the highest fidelity affordable.

EW Terminal Threats : The primary facility in any of the Services for simulating terminal threats to aircraft is the AFEWES facility at Ft Worth, TX. The facility provides a wide variety of terminal threats and has considerable linking experience.

4.2 EW SPJ Test Scenario

The test scenario consists of a single penetrating aircraft crossing into opposition airspace on a strike mission. The opposition target is protected by an IADS. Intelligence has allowed flight profiles to be planned which require the penetrating aircraft to only engage three surface-to-air missile batteries and one anti-aircraft artillery system during ingress and egress. The figure below illustrates a possible threat laydown for the scenario.
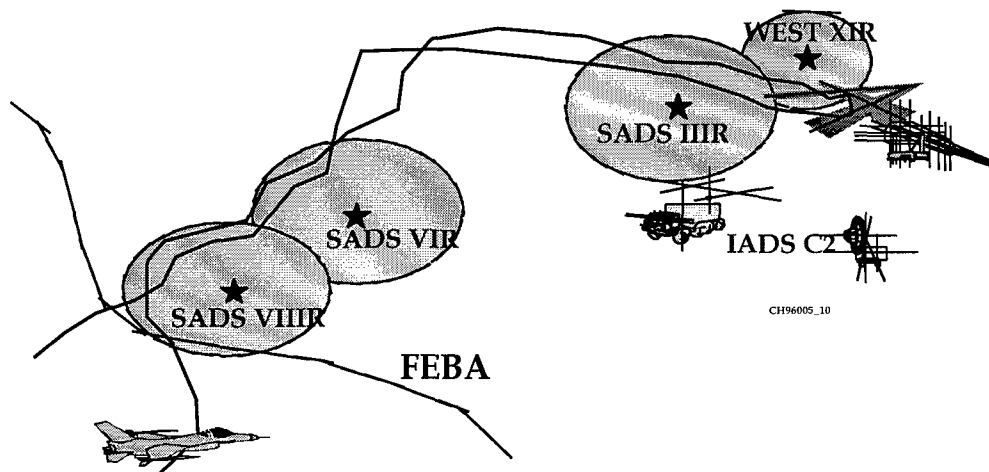
Figure 3 - SPJ Scenario

Phase I of the test will consist of a series of runs on an OAR against the threat laydown. The aircraft will fly a scripted profile across the simulated front echelon battle area (FEBA) and have engagements with the various threats. We will fly a single flight profile to collect a population of samples of performance data for a single reference test condition. The flight profile provides considerable opportunity for threat engagement and we expect to collect results ranging from break lock to simulated hits. Phase II of the test will duplicate the Phase I test while using an ADS environment. The Phase II block diagram below identifies the facilities and the exchanges between the facilities.
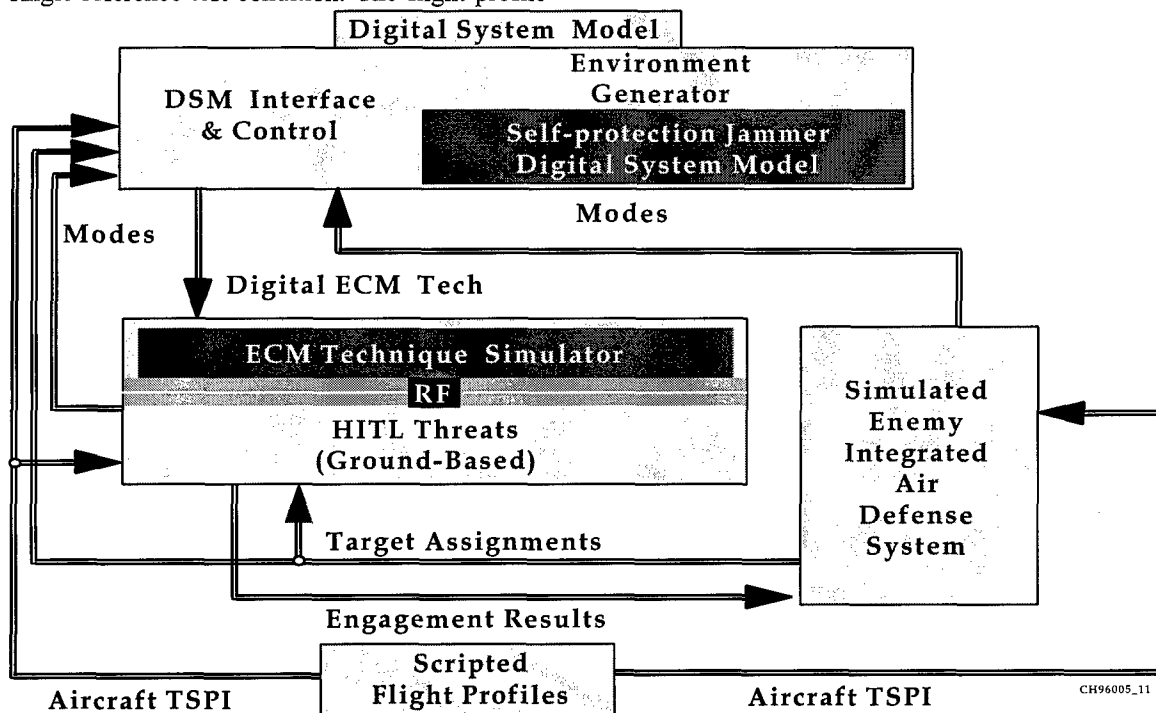

Figure 4 - Block Diagram of the Digital System Model (DSM) Test

Each block on the diagram above represents a potential facility in the DSM phase and the lines between the blocks are logical connections on digital communications links between the facilities. A key finding of our initial analyses was that to test a SPJ using ADS required the

tester to make one of two choices—multiple representations or single representation of the SUT.

Multiple Representations: The HLA EPF selected the choice of replicating or simulating the entire SPJ in each threat facility either as a digital model or as actual hardware. At the point when the threat radar initiates track mode, ownership of the SPJ will be transferred from the aircraft/SUT facility to the threat facility to perform simulations of the engagement and missile flyout and determine engagement results.

Single Representation: The JADS EW test adopted the choice of effectively splitting the digital and RF portions of the SPJ between the facilities. The upper box in the diagram represents the digital portion of the jammer. Electronic Counter-Measure (ECM) techniques selected by the jammer will be transmitted to the HITL facility as digital words and be simulated

in RF using the ECM technique simulator. The mode generated by the threat radar in response to the ECM technique will be captured and converted to a digital word which is transmitted back to the facility containing the SUT. This choice allows for high fidelity testing of any representation of the SUT at any level of system maturity. This choice does require instrumentation to verify that the transmitted modes and techniques are identical to the radiated signals in the HITL facility. We are currently planning to run the DSM and the aircraft scenario from the JADS Test Control and Analysis Center (TCAC) in Albuquerque, NM

Phase III of the test will replace the DSM with an actual SPJ integrated on an aircraft in an ISTF at ACETEF, Patuxent River, MD. The block diagram below shows this configuration.
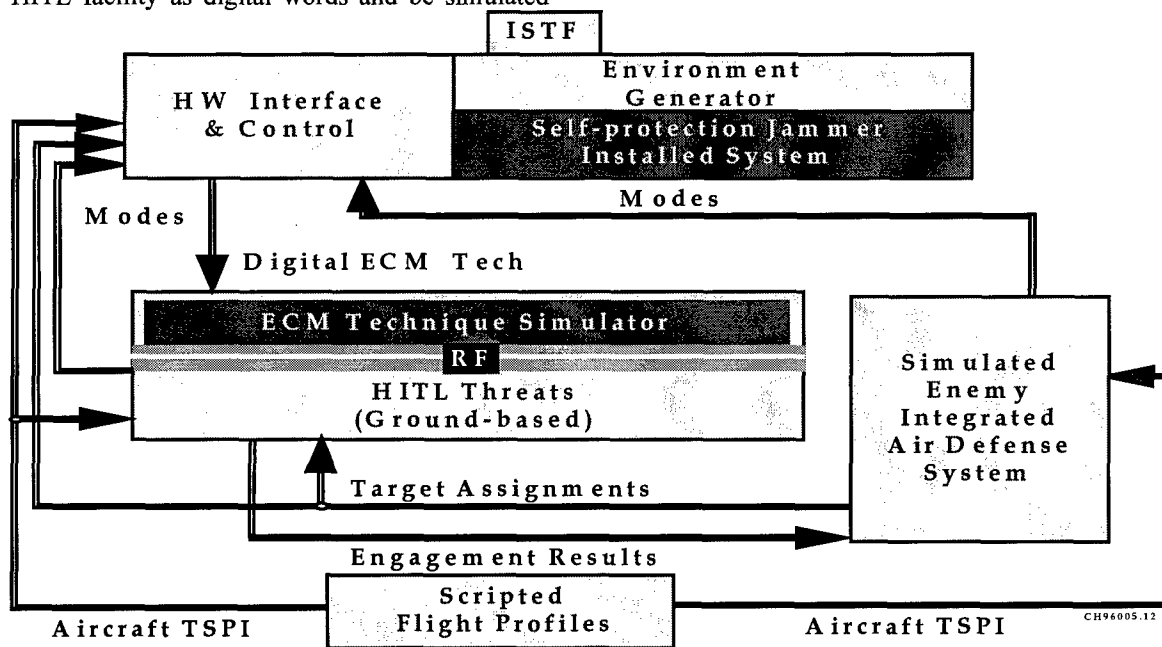

Figure 5 - Block Diagram of Installed System Test Facility (ISTF) Configuration

5. ADS Based EW Testing Issues and Concerns Addressed by JADS

In developing the EW test, JADS has identified a number of issues and concerns within the EW testing community regarding the use of ADS based testing. These concerns include, the perceived inability to create high fidelity digital

system models, the limitations of current communications networks to support pulse to pulse interactions, instrumentation requirements necessary to support ADS based testing, ADS induced errors, the ability to perform closed loop effectiveness testing of an installed system without flying on an OAR, and the affect of HLA on test design. Each of these issues and concerns

are being investigated by the EW test as described below.

Development of High-Fidelity Real-Time Digital Models. The EW test process identifies the need for high-fidelity models of the EW systems being developed. Ideally, these models will operate in real time. Although models of systems have been developed, they have not operated in real time and, therefore, cannot be used with real-time test assets. The approach adopted by the JADS EW team will provide a validation of the ability to develop such models and an approach for high-fidelity testing using such models.

Current Networking Limitations. Most analyses of the application of ADS technology to EW T&E have suggested an inability of current networking and ADS technology to support the pulse-to-pulse interactions in RF required of EW engagements. The approach adopted by the JADS test removes the need for networked RF engagements and eliminates the pulse-to-pulse transmission requirements by transmitting commanded threat modes and commanded jammer techniques between facilities. This approach does present challenges relating to signal representation and the timing and synchronization of the interactions; however, these challenges appear to be solvable within the current state of the art. The SPJ tests will verify the ability to overcome these issues.

Instrumentation Requirements for EW Tests Using ADS. Another concern of some EW testers is the requirement for verification that simulated RF signals actually match the technique or mode selected by the threat emitter or jammer in a test facility. The JADS approach to signal representation places more emphasis on this requirement. The JADS EW team has only identified two Open Air facilities with the real-time verification instrumentation for emitters and jammers. The SPJ test will ensure that appropriate instrumentation is installed in the selected test facilities and evaluate the value of the instrumentation for the test.

ADS-Induced Errors in Test Results. A key issue related to T&E in an ADS environment is the potential impact of the ADS environment on the test results. The JADS EW approach to

testing both in common non-ADS and ADS environments and then performing rigorous correlation analysis on the test results will provide a clear measure of the validity of the test results and will identify the specific performance measures which may have been impacted by the ADS environment. Detailed collection and analysis of network performance data in conjunction with the identification of potential invalid performance measures will allow for rigorous evaluation of cause and effect.

Closed-loop Effectiveness Testing on an Installed System. Another technical challenge for the proposed test concept is the integration of the ADS test environment with an ISTF to conduct closed-loop effectiveness of the SPJ installed on the actual aircraft. Currently, the primary ISTFs conduct open-loop testing of the operation of the system and electromagnetic interference and compatibility (EMI/EMC) testing of the systems in these facilities. This approach will represent a significant improvement to the capabilities of these facilities which is crucial to the full realization of the potential of ADS.

Applying HLA in the JADS EW Test Design Process. With the advent of the HLA, DoD supporting policy and implementation guidance, it became essential for JADS to incorporate HLA into the EW test to the maximum extent possible. JADS is working closely with DMSO, and currently participates in the HLA Architecture Management Group. With the experience and legacy information gained from the EPF in 1996, along with numerous other linking projects conducted by EW test facilities in recent years, JADS has a substantial base of experience to draw upon for developing a responsive test architecture. Early in the EW program definition phase, JADS elected to form an Integrated Product Team (IPT) comprised of representation from Open Air Range, HITL, and ISTF facilities and GTRI. Earlier this year, the IPT formed a team to develop define the EW test architecture and performance requirements following the HLA Federation Development and Execution Process Model (FEDEP). Based on the team familiarity with HLA methodology, data transfer requirements, and linking architectures, they drafted and iterated refinements to the JADS federation conceptual model. Throughput

requirements and performance characteristics for an EW RTI also have been developed.

6. Potential ADS EW Test Process extensions

JADS examined several possible test scenarios that would test both the utility of ADS in EW testing as well as specific test capabilities that could be realized by introducing ADS into the EW test process. Two specific enhancements being investigated are the extensions of the EW test process to use ADS early the in SPJ development cycle and again late in the development cycle just before flight test.

6.1 Potential Enhancements Using ADS Early in Development

Application of the ADS technology represented in the SPJ test holds considerable promise to enhance the current EW development and test process. The ability to perform high-fidelity DSM testing of conceptual systems has the potential to provide a realistic "test before you build" capability to EW system developments. The requirements of the conceptual system can be identified and evaluated in a high-fidelity test environment and key performance issues can be identified early in the development for special emphasis. Through the conduct of effectiveness testing of these conceptual systems in a more operationally representative environment, the developer will be able to identify failure modes of the system and provide solutions early in the development process where modification costs are lower. The application of the high-fidelity testing at each level of system maturity will continue to allow identification and evaluation of failure modes. Another potential advantage provided by the ability to develop and test a real-time digital model of the developing system is the potential ability to begin the mission software development and test earlier, thus reducing program development risk. Finally, this capability offers advantages in the planning and rehearsal of both DT&E and OT&E. The DSM test is designed to provide insights into these enhancements of the process.

6.2 Potential Enhancements Using ADS Late in Development

Another phase of the current EW development and test process which has the potential for enhancement is the testing of actual EW system assets installed on an aircraft. The ability to perform closed-loop effectiveness testing in an ISTF will provide a much better predictor of the performance of the system while capturing the effects of aircraft integration and EMI/EMC on system performance. An expansion of the initial program's environment to include integration of a domed simulator may possibly allow flight test rehearsal, high-fidelity testing against threats and threat laydowns which are not supported by the test ranges, and potentially the ability to improve flight testing at those critical "edge of the envelope" tests. The ISTF test will provide insights into these capabilities.

6.3 Potential ADS Solutions to Inherent Limitations in the EW Test Process

In Section 2 several inherent limitations to the current EW test process were identified. The first of these was the ability to correlate test results between test facilities and throughout testing during development of the system. ADS provides an approach to solving this limitation through a combination of common test environments and improving (perhaps simplifying) the application of test discipline throughout the entire system development process. A system developer will be able to select, using operational requirements for the system, test conditions early in the development cycle of the system and apply these conditions consistently across a common test environment throughout the development of the system. The representations of the SPJ will be tested in each phase under the same reference test condition (RTC) using a common test environment. Successful correlation of the JADS test results across the three phases will verify ADS is a solution to the limitation.

The second limitation to the current process was identified as resource limitations in EW testing. ADS provides several opportunities to address these limitations. From the standpoint of the threat environment, ADS provides the capability to expand the numbers of threats and the depth of the command and control network for the SUT beyond the capabilities of a single facility. A successful SPJ test in the proposed ADS

environment will provide this capability earlier in the process at a higher level of fidelity. Another resource limitation is in the number of test articles available for testing and the inability to test systems at low levels of maturity in a high-fidelity environment. The SPJ test evaluates the ability to link a single SUT to multiple threats at any level of system maturity. Another resource limitation is related to physical limitations of the open air test ranges. The ADS solution to this test constraint is to augment OAR with threats at other facilities and effectively expand the range. Current technical limitations on the use of live aircraft in the ADS environment limit the ability to address this issue on the OAR; however, the expanded capability offered by closed-loop testing using a linked ISTF will allow an expanded synthetic range in which to test the installed system.

The ADS approach to addressing fidelity limitations is the ability to link the SUT to threat simulations at other facilities which provide higher fidelity testing than available at the developer's primary test facility. Currently, this capability is achieved by sequential testing at multiple facilities. Sequential testing is limited by both correlation problems and test resources. A common linked test environment would provide a solution to these problems by allowing connection to assets at multiple facilities from a single location and access to higher fidelity test assets earlier in the test process.

7. Summary

This discussion has provided the details of the JADS EW SPJ test concept and the technical issues addressed by the test. Both the concept and the issues have been framed within the context of the EW test process. Shortfalls in the current test process such as correlation between test facilities, resource limitations, and fidelity limitations may be addressed by the use of ADS if the JADS EW test results show that ADS based testing provides acceptable data. The JADS test itself will examine two specific extensions to the EW test process. The first is a linking of an early representation of the SUT with high fidelity threats. The second examines the feasibility of coupling system effectiveness testing with traditional installed system performance testing.

Pursuing this test will cause JADS to address several EW test community concerns. Key concerns are the perceived inability to create high fidelity digital system models, the limitations of current communications networks to support pulse to pulse interactions, instrumentation requirements necessary to support ADS based testing, ADS induced errors, the ability to perform closed loop effectiveness testing of an installed system without flying on an OAR, and how HLA affects test design. JADS will be reporting on these concerns as well as providing lessons learned about how to develop an ADS based test using HLA processes and tools. All JADS data and material will be legacy for future EW test efforts.

8. References

[1] JADS JTF "Electronic Warfare Program Test Design 1995", undated.
[2] JADS JTF " Electronic Warfare Test Analysis Plan for Assessment (APA)", May 1996.

Author's Biographies

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D. Currently Applicable Classification Level: Unclassified

E. Distribution Statement A: Approved for Public Release

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